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THE EFFICIENCY OF THE 'ROLLA MUNICIPAL POWER
PLANT.'

by

True Walter Blake.

Otto Allen Lunak.

T248

A

T H E S I S

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY
OF MISSOURI.

in partial fulfillment of the work required
for the

D E G R E E O F

BACHELOR OF SCIENCE IN MINE ENGINEERING

Rolla, Mo.

1911.

Approved by

Austin L. McRae

Professor of Physics.

11861

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Efficiency of the Rolla Municipal Power Plant.

Object.

The object of this thesis is to determine the efficiency of the separate units and of the plant as a whole under actual normal working conditions.

Location.

The plant is located near the central part of the city of Rolla and on the St. Louis and San Francisco Railway.

Plant.

The plant consists of:-

- 1 - 80 H.P. O'Brien horizontal fire-tube boiler having a maximum working pressure of 100 pounds gage.
- 1 - 100 H.P. Atlas horizontal fire-tube boiler having a maximum working pressure of 100 pounds gage.
- 1 - Cochrane exhaust steam feed-water heater.
- 1 - 160 H.P. Hamilton Corliss engine, cylinders 14" x 21" making 200 R.P.M.
- 1 - 66 H.P. Fischer engine.
- 1 - 100 K.W. 250 volt, D.C. Westinghouse, 6 pole dynamo, direct connected and over compounded.
- 1 - 45 K.W. 240 volt, D.C. Triumph Electric Co. 4 pole belt driven dynamo, making 875 R.P.M.
- 1 - Laidlaw-Dunn-Gordon cross-compound belt driven air compressor, delivering 203 cubic feet of free air per minute at 14.3 pounds pressure per square inch and at 60 degrees Fahrenheit. The cylinders are 16" X 9" X 12".

- 1 - air lift pump capable of lifting 290 gallons of water per minute with a lift of 181 feet.
 - 2 - 4" Worthington centrifugal pumps capable of working against a pressure of 125 pounds per square inch.
 - 1 - White Italian Marble switchboard.
 - 1 - Blue Vermont Marble switchboard.
 - 1 - 8" drilled well, 930 feet deep with water standing at 181 feet from the surface.
 - 1 - underground concrete reservoir 24 feet in diameter and 12 feet deep, holding 40000 gallons.
 - 1 - concrete standpipe, 20 feet in diameter and 30 feet high, holding 70000 gallons of water. This standpipe is located on a hill giving a 127 foot head.
- Necessary pipe line.

APPARATUS USED IN TESTING PLANT.

Boiler.

- 1 - one inch National hot water meter for determining the amount of water fed to the boiler. Calibrated before using.
- 1 - centigrade thermometer for determining the temperature of the feed water.
- 1 - Fahrenheit thermometer, reading to 700 degrees, to determine the temperature of the flue gases.
- 1 - Ellison boiler draft gage reading to 1/100 of an inch for determining the draft in the boiler stack.
- 1 - Fairbanks scale for weighing coal.
- 1 - barrel holding 200 pounds of coal used for weighing the same.

3.

1 - Parr calorimeter for determining the calorific power of the coal.

Engine.

1 - Crosby steam indicator with spring giving a scale of one inch equals 50 pounds pressure.

Dynamo.

1 - Westinghouse ammeter. Scale 0 to 600 amperes.

1 - Westinghouse voltmeter. Scale 0 to 300 volts.

These instruments were calibrated before using.

Air Compressor.

1 - galvanized iron drum 18" in diameter and 5 feet long with a 3" orifice, for the measurement of capacity

1 - manometer for reading the pressure in the tank.

1 - Centigrade thermometer for obtaining the temperature of the air in the tank.

1 - receiver pressure gage.

Air Lift Pump.

Obtained the data from Prof. Harris.

Centrifugal Pumps.

No tests were made.

METHODS OF MAKING TESTS.Boiler.

Tests began at 7:00 P.M. and ended at 5:00 A.M., making the length of test ten hours.

The alternate method was followed, it being as follows:- The ash pit was cleaned and fire in good working condition, note being taken of the condition of the fire on the grate and the water level in the boiler. These conditions were approximately the same at the finish of the test as they were at the beginning. The water level in boiler was kept as near constant as possible.

The coal was weighed, as used, in a barrel holding 200 pounds.

The firing was done in the usual manner by the usual fireman.

The quantity and temperature of the feed water was determined by a hot water meter and thermometer respectively readings being taken and recorded every 15 minutes.

The draft in the stack was determined in terms of inches of water by means of an Ellison flue draft gage, readings being taken every 15 minutes.

The temperature of the flue gases was determined by means of a thermometer, readings being taken every 15 minutes.

The steam pressure and temperature of the feed water was kept as nearly constant as possible throughout the run. As the feed water was heated by means of

exhaust steam, the amount of feed water used increased or lowered the temperature; the faster the water was fed to the boiler, the lower the temperature would be; the slower, the higher would be its temperature. Accordingly there was somewhat of a variation in the temperature of the feed water.

The two boilers were connected together, so the efficiencies show efficiencies of the two boilers working in parallel.

Engine and Dynamo.

Indicator cards were taken every 15 minutes throughout the run.

An ammeter and voltmeter were used for getting the output of the dynamo. Readings were taken every 15 minutes and recorded.

The I.H.P. was determined by working out the indicator cards with a planimeter, getting the M.E.P. from this.

The water taken out of the steam separator just above the steam chest was measured.

Air Compressor.

The orifice drum was connected to the receiver tank, the valve in the pipe line to the well being left open to act as a safety device in case the valve outlet of the receiver into the tank should become closed. The compressor was started and run until it became heated to running temperature and the air throttled by the valve

between the receiver tank and the orifice drum until the pressure in the receiver tank reached about 140 pounds pressure per square inch, the valve in the air line to the well being gradually closed. When the valve governing the flow of air to the orifice tank had become adjusted so that the pressure remained about 130 pounds per square inch, the valve in the pipe line to the well was closed.

The speed of the compressor, the pressure in the receiver, and the temperature and pressure in the orifice drum were taken simultaneously and recorded. Readings were then taken at intervals of a few minutes until the pressure in the receiver, and the temperature and pressure in the orifice tank became constant.

Air Lift Pump.

The air compressor was started, the air line to the well being open. Time was noted when water began flowing from the well into the reservoir and also when the air was shut off from entering the well. The depth of the water in the reservoir was then measured and the quantity of water in gallons per minute was calculated by means of the diameter of the reservoir.

Centrifugal Pumps.

These pumps pump 433 gallons per minute against a 127 foot head.

DATA.Boiler.

These tests were made Feb. 10, 1911.

| TIME | WGT. OF COAL | METER READING | FEED WATER TEMP. | STEAM GAGE | FLUE DRAFT | FLUE TEMP. |
|-------|-----------------|------------------|------------------------|---------------|---------------|---------------|
| 7:00 | 300 | 7144 | | 87 | | |
| 7:15 | 400 | 7250 | 80°C | 96 | .33 | 480°F |
| 7:30 | 400 | 7334 | 87 | 102 | .45 | 600 |
| 7:45 | 800 | 7410 | 92 | 97 | .31 | 470 |
| 8:00 | | 7498 | 85 | 95 | .45 | 535 |
| 8:15 | | 7596 | 81 | 97 | .34 | 610 |
| 8:30 | | 7734 | 70 | 95 | .38 | 460 |
| 8:45 | | 7840 | 70 | 97 | .32 | 545 |
| 9:00 | | 7949 | 68 | 93 | .43 | 510 |
| 9:15 | 600 | 8085 | 68 | 95 | .29 | 450 |
| 9:30 | | 8185 | 65 | 86 | .43 | 560 |
| 9:45 | 400 | 8325 | 56 | 100 | .29 | 580 |
| 10:00 | | 8461 | 70 | 92 | .42 | 540 |
| 10:15 | 400 | 8588 | 85 | 93 | .32 | 620 |
| 10:30 | 400 | 8726 | 85 | 90 | .49 | 570 |
| 10:45 | | 8854 | 88 | 97 | .34 | 530 |
| 11:00 | 400 | 8940 | 94 | 93 | .40 | 495 |
| 11:15 | | 9035 | 94 | 97 | .31 | 515 |
| 11:30 | | 9110 | 94 | 100 | .46 | 566 |
| 11:45 | 600 | 9220 | 93 | 92 | .35 | 522 |
| 12:00 | | 9310 | 93 | 92 | .38 | 482 |
| 12:15 | | 9400 | 91 | 97 | .31 | 650 |
| 12:30 | | 9520 | 72 | 90 | .41 | 404 |
| 12:45 | | 9654 | 61 | 98 | .30 | 530 |
| 1:00 | 800 | 9784 | 65 | 88 | .50 | 490 |
| 1:15 | | 9828 | 64 | 101 | .32 | 600 |
| 1:30 | | 10074 | 62 | 94 | .40 | 420 |
| 1:45 | | 10165 | 70 | 95 | .33 | 500 |
| 2:00 | 200 | 10255 | 75 | 100 | .47 | 510 |
| 2:15 | 200 | 10304 | 93 | 95 | .30 | 480 |
| 2:30 | | 10380 | 82 | 97 | .34 | 490 |
| 2:45 | | 10468 | 54 | 90 | .27 | 485 |
| 3:00 | | 10555 | 50 | 94 | .30 | 476 |
| 3:15 | | 10606 | 53 | 100 | .34 | 515 |
| 3:30 | | 10655 | 71 | 95 | .29 | 426 |
| 3:45 | 200 | 10680 | 70 | 100 | .33 | 510 |
| 4:00 | | 10715 | 78 | 98 | .32 | 425 |
| 4:15 | | 10760 | 70 | 90 | .33 | 445 |
| 4:30 | 200 | 10828 | 60 | 93 | .31 | 410 |
| 4:45 | | 10845 | 60 | 99 | .30 | 420 |
| 5:00 | | 10865 | 70 | 92 | .32 | 420 |
| Av. | 6300# | 3721 gallons | 74.7°C | 95.2# | .357" | 506.05°F |

Engine and Dynamo.

These tests were made Feb. 10, 1911.

| TIME | I.H.P. | VOLTS | AMPERES | H.P. OUTPUT OF DYNAMO | EFF. OF TWO COMBINED |
|-------|--------|-------|---------|-----------------------------|-------------------------|
| 7:00 | 95.0 | 222 | 235 | 70.6 | 74.2 |
| 7:15 | 94.1 | 224 | 250 | 75.7 | 80.4 |
| 7:30 | 106.9 | 233 | 275 | 86.5 | 80.9 |
| 7:45 | 102.5 | 232 | 260 | 81.5 | 79.3 |
| 8:00 | 90.4 | 234 | 225 | 71.1 | 78.8 |
| 8:15 | 83.8 | 224 | 225 | 68.3 | 81.6 |
| 8:30 | 80.4 | 230 | 215 | 66.8 | 82.9 |
| 8:45 | 79.9 | 230 | 210 | 65.3 | 81.9 |
| 9:00 | 87.2 | 230 | 205 | 63.8 | 73.0 |
| 9:15 | 67.4 | 228 | 170 | 52.6 | 77.9 |
| 9:30 | 71.5 | 226 | 175 | 53.3 | 74.5 |
| 9:45 | 55.7 | 228 | 145 | 44.8 | 80.4 |
| 10:00 | 140.6 | 218 | 130 | 37.0 | 45.5 |
| 10:15 | 123.2 | 220 | 118 | 35.2 | 46.4 |
| 10:30 | 133.8 | 219 | 103 | 30.5 | 42.9 |
| 10:45 | 128.9 | 218 | 99 | 29.2 | 43.6 |
| 11:00 | 120.0 | 220 | 87 | 25.8 | 44.0 |
| 11:15 | 120.7 | 220 | 85 | 25.3 | 43.3 |
| 11:30 | 117.1 | 222 | 80 | 24.1 | 43.6 |
| 11:45 | 114.0 | 220 | 70 | 20.8 | 40.0 |
| 12:00 | 114.0 | 218 | 75 | 22.2 | 41.4 |
| 12:15 | 114.0 | 220 | 67 | 19.7 | 40.9 |
| 12:30 | 89.9 | 222 | 60 | 18.0 | 29.8 |
| 12:45 | 85.2 | 224 | 55 | 16.7 | 29.9 |
| 1:00 | 87.4 | 221 | 52 | 15.6 | 27.9 |
| 1:15 | 81.5 | 224 | 50 | 15.1 | 29.3 |
| 1:30 | 83.2 | 220 | 49 | 14.6 | 28.1 |
| 1:45 | 82.6 | 222 | 50 | 15.0 | 28.8 |
| 2:00 | ---- | 224 | 51 | 15.4 | ---- |
| 2:15 | ---- | 222 | 47 | 14.1 | ---- |
| 2:30 | 76.3 | --- | -- | ---- | ---- |
| 2:45 | 21.0 | 224 | 45 | 13.6 | 64.7 |
| 3:00 | 20.5 | 226 | 48 | 14.7 | 71.6 |
| 3:15 | 22.1 | 226 | 45 | 13.7 | 61.9 |
| 3:30 | 21.6 | 224 | 45 | 13.6 | 63.0 |
| 3:45 | 22.6 | 226 | 45 | 13.7 | 60.5 |
| 4:00 | 23.7 | 224 | 45 | 13.6 | 57.4 |
| 4:15 | 18.9 | 224 | 51 | 15.4 | 81.5 |
| 4:30 | 20.5 | 223 | 48 | 14.5 | 70.7 |
| 4:45 | 23.7 | 224 | 50 | 15.2 | 63.7 |
| 5:00 | 25.7 | 222 | 55 | 16.5 | 64.1 |

Av.

224 V

109.9 A

Air Compressor.

These tests were made May 6, 1911.

| TIME | TEMP. IN ORIFICE OF TANK | MANOMETER READING | RECEIVER PRESSURE | R.P.M. |
|-------|--------------------------------|----------------------|----------------------|--------|
| 11:20 | 64°C | 2.9"H ₂ O | 127.5 [#] | 100 |
| 11:30 | 75 | 2.8 | 127 | 100 |
| 11:32 | 76 | 2.8 | 127 | 100 |
| 11:35 | 79 | 2.8 | 127 | 100 |
| 11:45 | 78°C | 2.6"H ₂ O | 124 | 100 |
| 11:47 | 81 | 2.65 | 126 | 100 |
| 11:53 | 83.5 | 2.65 | 127 | 100 |
| 11:55 | 84.5 | 2.8 | 127 | 100 |

H.P. without compressor is 48.79 (from indicator card)

H.P. with compressor is 115.99 (from indicator card)

Diameter of orifice - 3 inches.

Barometer - 29" Hg -14.24[#] per square inch.

Temperature of atmosphere - 15°C - 59°F.

H.P. absorbed by compressor is 115.99 - 48.79 is 67.20 H.P.

Air Lift.

Owing to certain conditions we were unable to make tests on the air lift and centrifugal pumps. Prof. Harris however gave us the data that he had on the air lift and from his data we made our calculations.

Water lifted per minute-----290 gallons

Height lifted-----181 feet

Output of the air compressor taken to be the same as that found in the volumetric test.

METHODS OF CALCULATIONS.Boiler.

First found the number of pounds of water apparently evaporated from feed water per pound of coal as fired.

Gallons of water fed to the boiler-----3721

Average temperature of feed water-----166.5°F

Weight of one cubic foot of water at

the above temperature-----60.74#

Pounds of water fed to the boiler

3721 X 60.74 -----30207.3

1728

Total amount of coal as fired-----6300#

Pounds of water evaporated per pound of coal

as fired 30207 -----4.8#
6300

To find the number of pounds of water evaporated (apparently) per pound of dry coal as fired, from actual feed water temperature.

By analysis the coal was found to contain 5.10% moisture, so pounds of water apparently evaporated under conditions given above, equals

$$\begin{array}{r} 30207 \times 100 \\ 6300 \times 94.9 \end{array} \quad \text{-----} \quad 5.05 \text{ pounds}$$

To find the equivalent number of pounds of water evaporated per pound of coal as fired, evaporating from and at 212°F.

Consider the steam to be commercially dry.

Average temperature of feed water-----166.5°F

Sensible heat of liquid above 32°F ----135.0

Total heat of water above 32°F under pressure of

(95.2 plus 14.2)=109.4 pounds abs.-----1183.4

Total heat less the sensible heat above 32 F

equals 1183.4 - 135.0 = 1048.4

Latent heat of vaporization equals-----966.1

Factor of evaporation = $\frac{1048.4}{966.1} = 1.085$

4.8 X 1.085 = 5.21 pounds of water evaporated from and at 212°F.

To find the boiler horse power.

A standard boiler horse power equals 34.5 pounds of water evaporated per hour from and at 212°F.

Total equivalent of water evaporated from and at

212°F = 30207 X 1.085 = 32774.6 pounds.

Then boiler H.P. = $\frac{32774.6}{10 \times 34.5} = 95.0 \text{ H.P.}$

To find the boiler efficiency.

Boiler efficiency equals the theoretical heat needed to evaporate a certain amount of water divided by that actually used.

The B.T.U.s required to evaporate 32774.6 pounds of water from and at 212°F = $32774.6 \times 966 = 31627263.6$ B.T.U.s
This is the theoretical amount of heat needed.

Note: The factor "966" equals the B.T.U.s needed to evaporate one pound of water from and at 212°F into steam at the same pressure.

Heat units in the dry coal used in this run equals 11150 B.T.U.s per pound.

Total B.T.U.s = $11150 \times 6300 = 70245000$ B.T.U.s

The heat units left in the ash must be taken into account.

Total ash -----1071 pounds.

B.T.U.s per pound of ash-----1347

Total B.T.U.s in ash = $1071 \times 1347 = 1442637$

Total available B.T.U.s = $70245000 - 1442637 =$

| | | |
|-------------------------------|-------------------|---------|
| | = 68802363 | |
| | <u>31627263.6</u> | |
| Boiler efficiency then equals | | = 45.8% |
| | 68802363 | |

Engine.

To find the indicated horse power (I.H.P.)

Obtain the area of the cards by means of a planimeter in units of the square inch.

The "mean effective pressure" (M.E.P.) is found by dividing one half the total area of card, which is in square inches, by the length of the base in terms of the unit "inch", multiplying this by the scale of the spring used (50 pounds per square inch).

Thus I.H.P. = $\frac{\text{M.E.P.} \times \text{length in feet} \times \text{piston area in}}$

33000

$\frac{\text{square inches} \times \text{number of strokes per minute}}$

or I.H.P. = $\frac{\text{PLAN}}{33000}$

Dynamo.

To find the horse power and output
 $\frac{\text{volts} \times \text{amperes}}$

H.P. output = 746

Note: "746" equals the number of watts in one horse power.

Engine and Dynamo.

To find the efficiency of engine and dynamo combined.

Efficiency = $\frac{\text{H.P. output of dynamo}}{\text{I.H.P. of engine}}$

Air Compressor.To find the volumetric efficiency.

$$P = \text{piston displacement per stroke} = \frac{\pi D^2}{4} \times L - \left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4} \right) \times L$$

$$= 2.77 \text{ Cu. Ft.}$$

D = piston diameter = 16"

d = diameter of piston rod = 2"

L = length of stroke = 12"

$$Q = C \times .1632 d^2 \sqrt{\frac{i}{t} \cdot p_a}$$

When

Q = weight of air passing per second.

C = the experimental coefficient.

d = diameter of the orifice in inches.

i = pressure as read on the gage in inches of water.

t = absolute temperature Fahrenheit inside of drum.

 p_a = air pressure in pounds per square inch inside drum.

$$\text{Volume} = \frac{Q}{\text{weight per cu. ft.}} = \text{volume per second.}$$

$$E = \text{efficiency} = \frac{\text{volume of air per minute}}{\text{piston displacement per minute}}$$

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-------------|---|---------|-------------|---|---------|---------------------------------|----------------------------|
| TIME | DIAM RPM | ORIFICE | LOG DIAM | 2 LOG DIAM | i | LOG i | TEMP ^{abs.} F. |
| 11:20 | 100 | 3" | .47712 | .95424 | 2.9 | .46240 | 607.8 |
| 11:30 | 100 | 3 | .47712 | .95424 | 2.8 | .44716 | 627.6 |
| 11:32 | 100 | 3 | .47712 | .95424 | 2.8 | .44716 | 629.4 |
| 11:35 | 100 | 3 | .47712 | .95424 | 2.8 | .44716 | 634.8 |
| 11:45 | 100 | 3 | .47712 | .95424 | 2.6 | .41497 | 633.0 |
| 11:47 | 100 | 3 | .47712 | .95424 | 2.65 | .42325 | 638.4 |
| 11:53 | 100 | 3 | .47712 | .95424 | 2.65 | .42325 | 642.9 |
| 11:55 | 100 | 3 | .47712 | .95424 | 2.8 | .44716 | 644.7 |
| 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| LOG TEMP | $\frac{1}{2}(\text{LOG } i + \text{LOG } p_a - \text{LOG } \text{TEMP.})$ | C | LOG Q | LOG $V_a = \text{LOG } Q - \text{LOG } W_a$ | LOG RPM | LOG E = +LOG P -LOG IN 14 | LOG IN 13 |
| 2.78376 | 1.41607 | .597 | 1.13715 | 2.26662 | 2.44248 | 1.82414 | 66.70% |
| 2.79768 | 1.40149 | .597 | 1.12257 | 2.25204 | 2.44248 | 1.80956 | 64.50% |
| 2.79893 | 1.40087 | .597 | 1.12295 | 2.25242 | 2.44248 | 1.80994 | 64.56% |
| 2.80264 | 1.39901 | .597 | 1.12009 | 2.24946 | 2.44248 | 1.80698 | 64.12% |
| 2.80140 | 1.38354 | .597 | 1.10462 | 2.23409 | 2.44248 | 1.79151 | 61.87% |
| 2.80509 | 1.38583 | .597 | 1.10691 | 2.23638 | 2.44248 | 1.79390 | 62.22% |
| 2.80814 | 1.38431 | .597 | 1.10539 | 2.23486 | 2.44248 | 1.79238 | 62.00% |
| 2.80936 | 1.39565 | .597 | 1.11673 | 2.24620 | 2.44248 | 1.80372 | 63.64% |

P = 2.77 Cu. Ft.

Log P = .44248

$p_a = 14.24^{\frac{1}{2}}$ per sq. in. Log $p_a = 1.15351$

$W_a = \frac{14.24 \times 144}{53.17 T_a} = .07422$ Log $W_a = 2.87053$

$T_a = 15^{\circ}\text{C} = 519.6^{\circ}\text{F}_{\text{abs.}}$

Log Q = Log C + Log .1632 + Log in 10 + Log in 5 + Log 60

Log C = 1.77597

Log .1632 = 1.21272

Log 60 = 1.77815

Average efficiency = 63.7%

To find the mechanical efficiency of the air compressor.

The work output is equal to $PV \log R$.

$$R = \frac{127 \quad 14.24}{14.24} = 9.92$$

$$\log R = 2.29455$$

$$P = 14.24 \times 144$$

$$V = 2.77 \times 100 \times .637 = 176.45$$

$$\text{H.P. output} = PV \log R \text{ divided by } 33000 =$$

$$= \frac{14.24 \times 144 \times 2.77 \times 100 \times .637 \times 2.29455}{33000} = 25.16$$

The work absorbed by the compressor equals the horse power developed by the engine with air compressor running under its normal working conditions minus the horse power developed by engine when compressor was not running, assuming however that the electric load is the same in both cases.

$$\text{H.P. with compressor} = 115.99$$

$$\text{H.P. without compressor} = 48.79$$

$$\text{H.P. absorbed by compressor} = 67.20$$

$$\text{Efficiency} = \frac{\text{output}}{\text{intake}} = \frac{25.16}{67.20} = 37.44\%$$

Air Lift Pump.

To find the efficiency.

H.P. theoretically needed to lift the water

$$= \frac{290 \times 181 \times 8.33}{33000} = 13.25\%$$

17.

$$\begin{aligned} \text{H.P. supplied to do this work equals } & \frac{PV \log R}{33000} \\ = & \frac{14.24 \times 144 \times 277 \times .637 \times 2.29455}{33000} = 25.16 \\ \text{Efficiency} = & \frac{13.25}{25.16} = 52.66\% \end{aligned}$$

To find the total efficiency of the whole plant for the ten hour run from 7:00 P.M. to 5:00 A.M.

This efficiency will be foot pounds equivalent of the work done in the run divided by the foot pounds equivalent of the B.T.U.s in the coal as fired.

$$\begin{aligned} & \text{Foot pounds of work done by compressor in lifting} \\ & \text{water. Compressor running from 9:55 to 2:30 (275 mins)} \\ & = 290/7.48 \times 181 \times 62.5 \times 275 = 120610000 \end{aligned}$$

Foot pounds of work done by pumps in lifting water.

$$\begin{aligned} & \text{Pumps running from 9:55 to 12:25 (150 minutes).} \\ & = 433/7.48 \times 127 \times 62.5 \times 150 = 68921700 \end{aligned}$$

Equivalent foot pounds for the watts delivered by the generator

$$= \frac{224 \times 109.9}{1000} \times 1.35 \times 33000 \times 10 \times 60 = 658016600$$

Equivalent foot pounds of coal as fired

$$= 11150 \times 6300 \times 778 = 54650000000$$

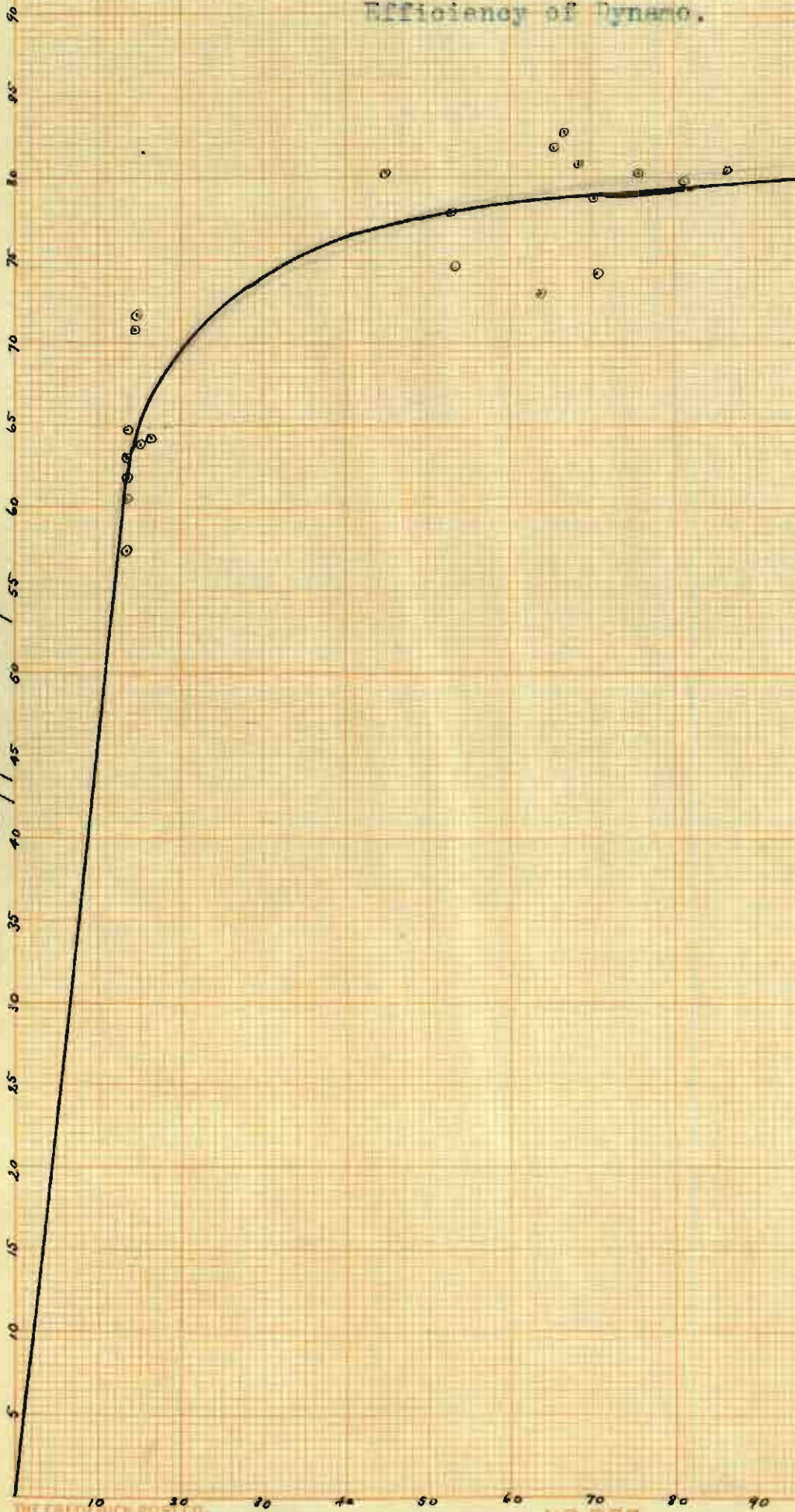
Total efficiency of plant

$$= \frac{120610000 + 68921700 + 658016600}{54650000000} = 1.55\%$$

Feb. 10, 1911

Horse power output of dynamo
and
Efficiency of dynamo.

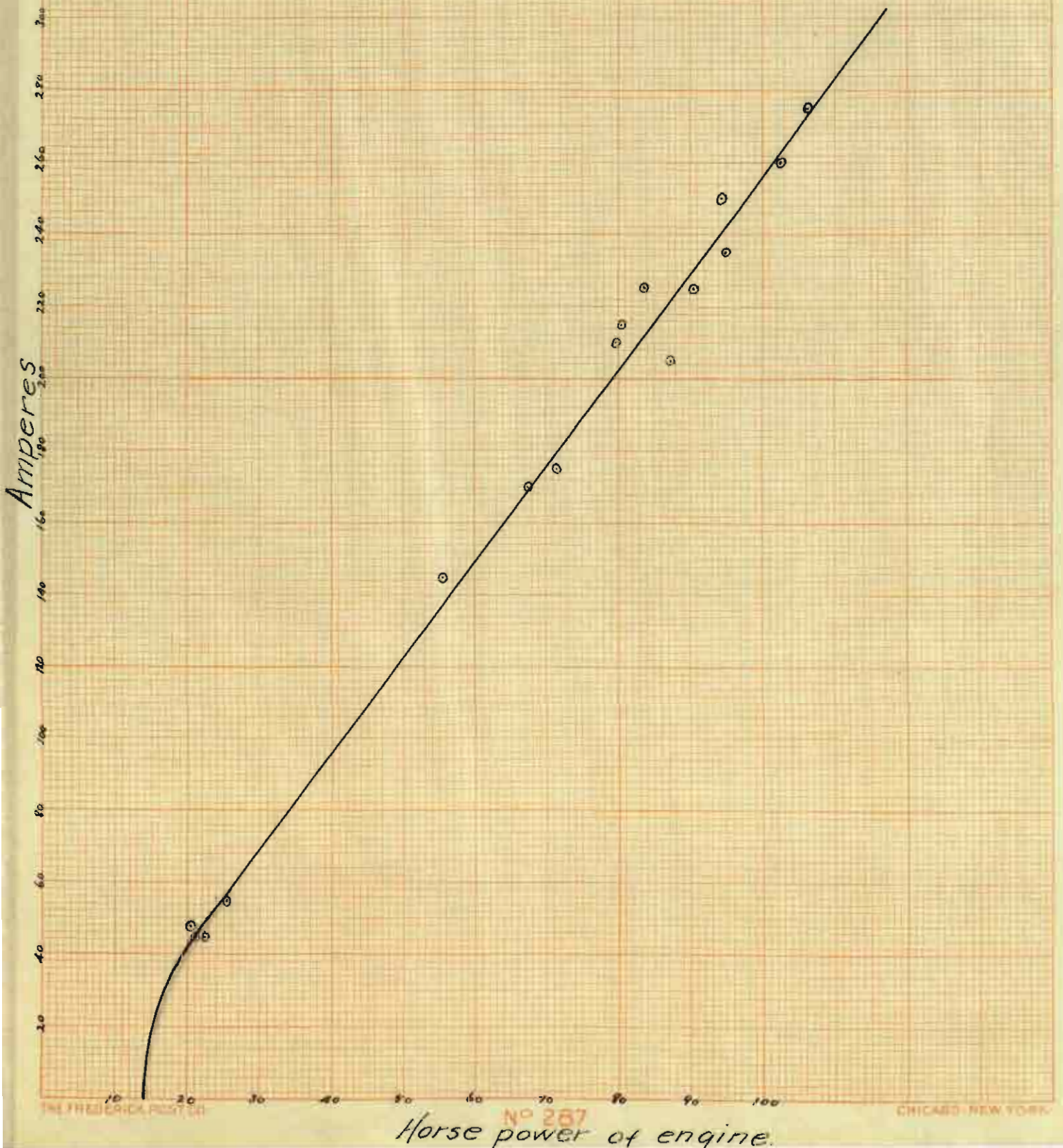
Efficiency.



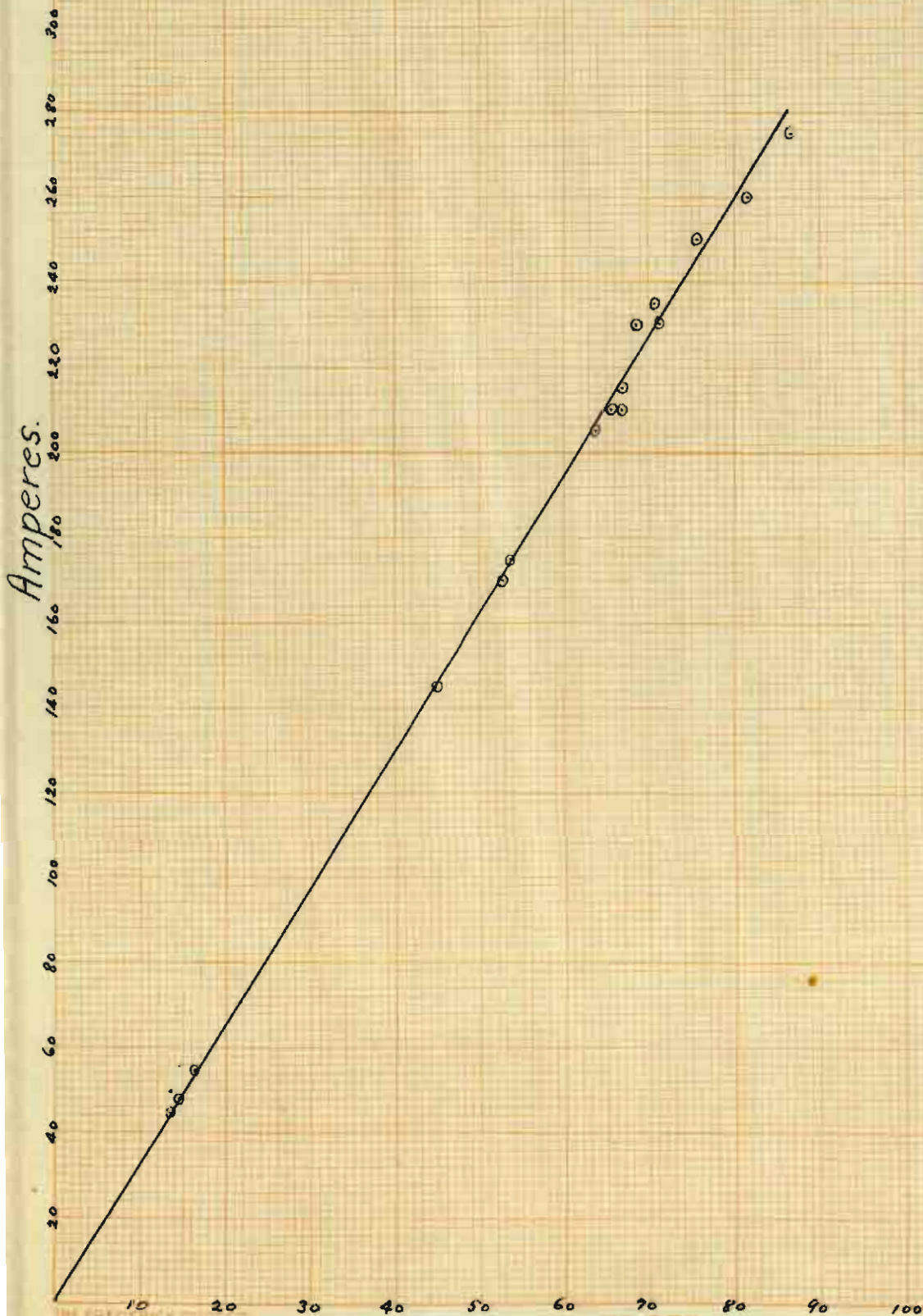
No 287

H.P. of Dynamo

Ampères
and
I.H.P. of engine.



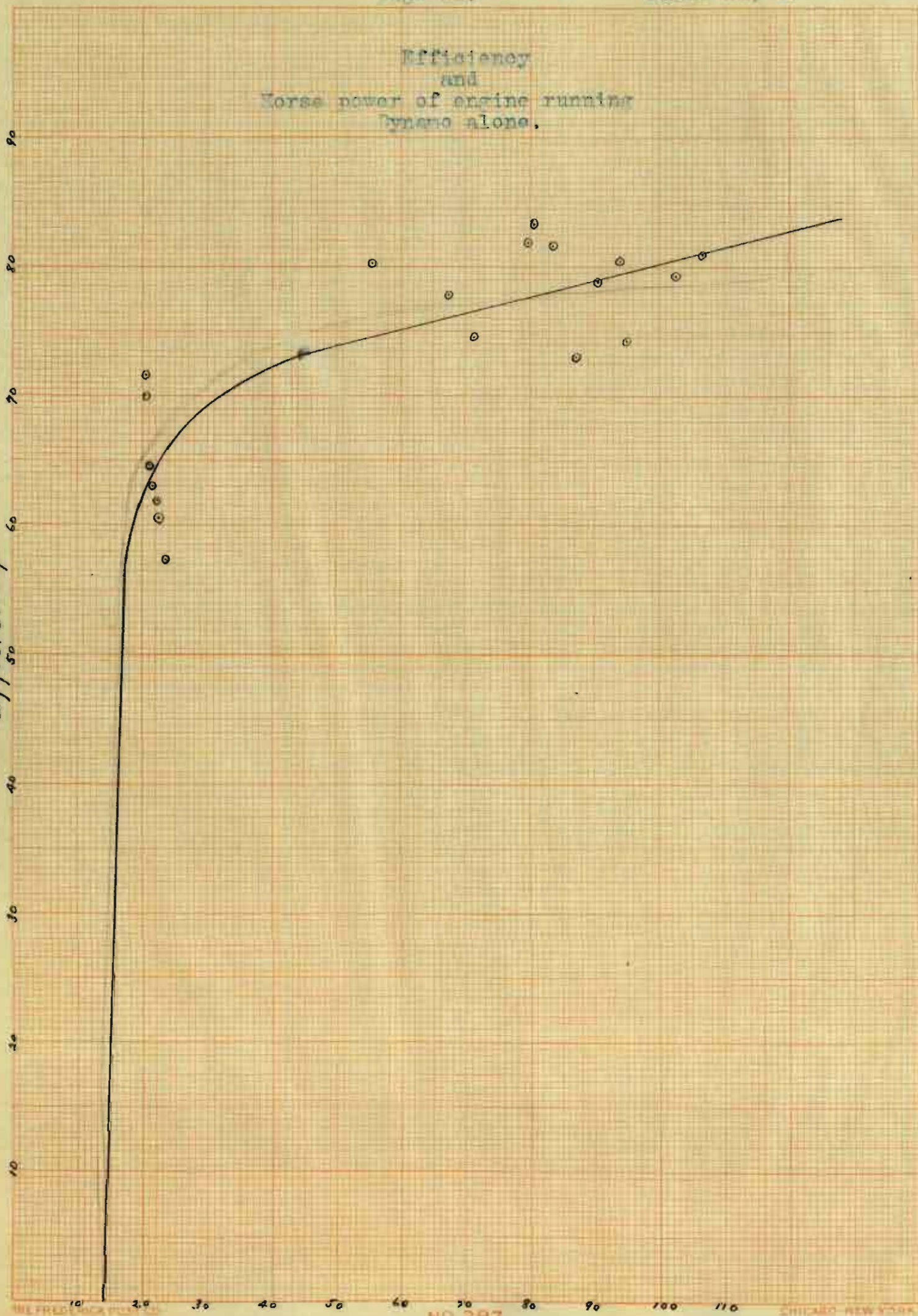
Amperes
and
Horse power



No 287
Horse Power

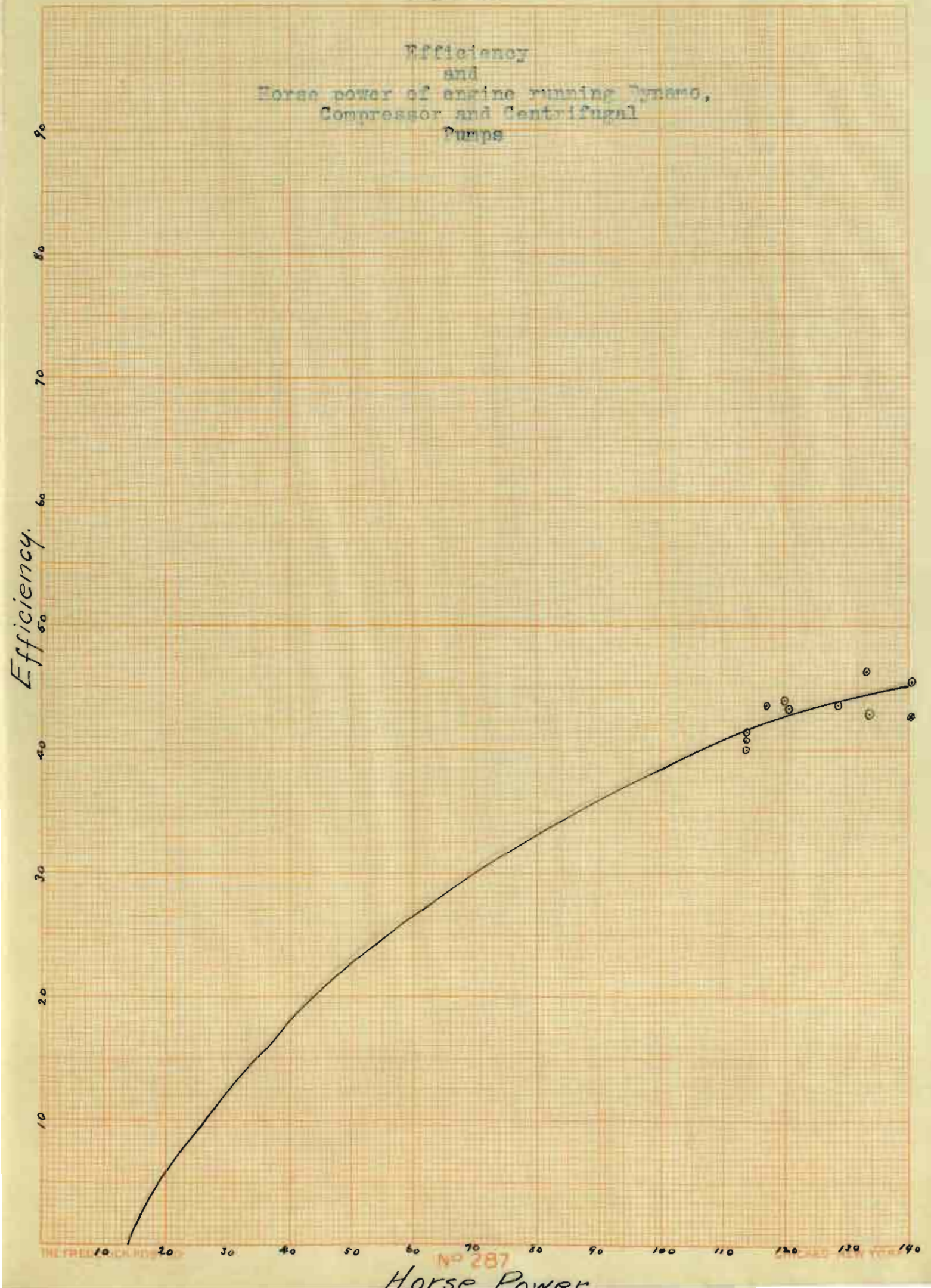
Efficiency
and
Horse power of engine running
Dynamo alone.

Efficiency.

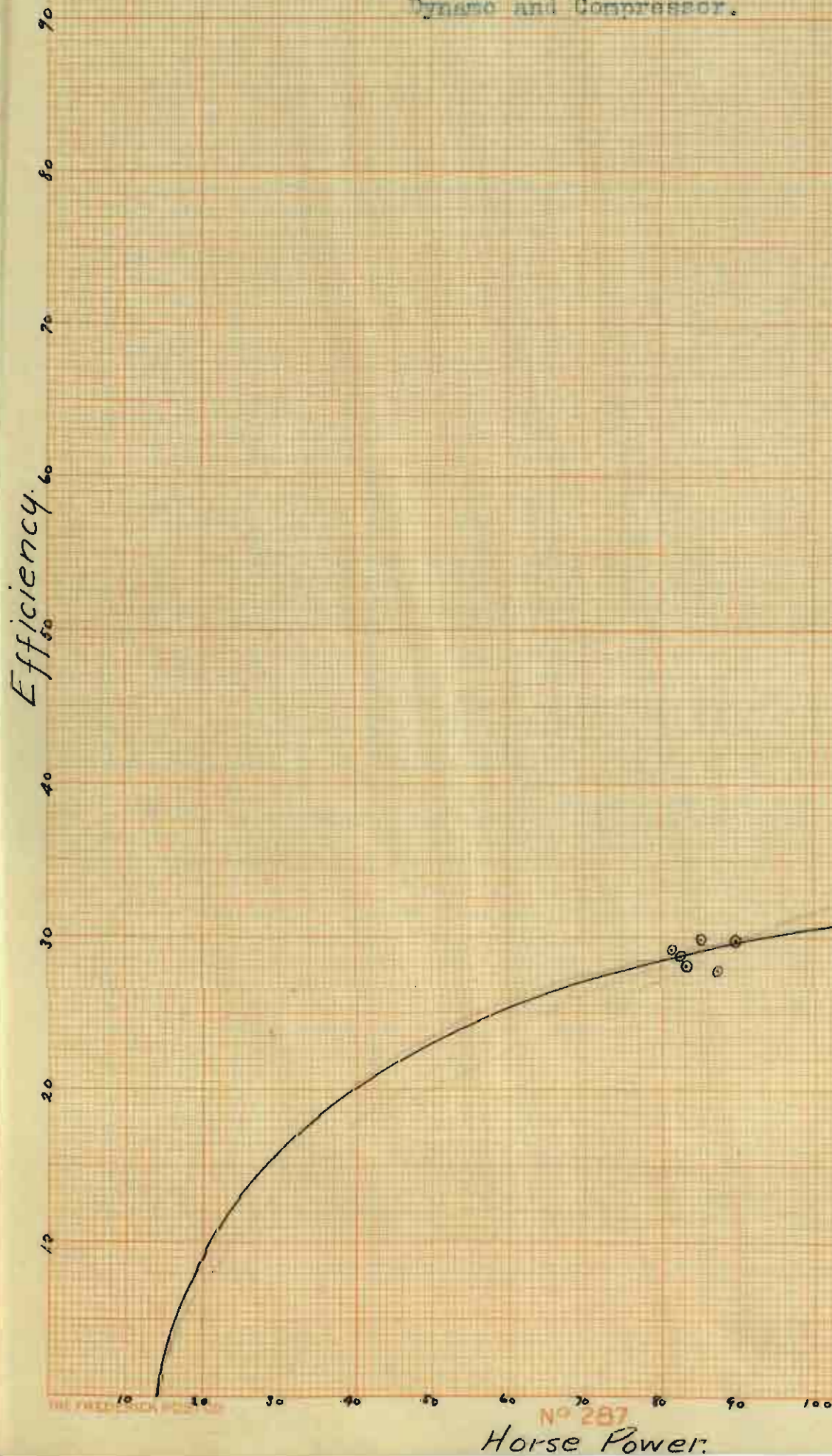


Nº 287
Horse Power

Efficiency
and
Horse power of engine running Dynamo,
Compressor and Centrifugal
Pumps



Efficiency
and
Horse power of engine running
Dynamo and Compressor.



Explanation of Curves.Curve No. 1.

This curve represents the horse power equivalent of output of the dynamo plotted against the efficiency of the engine and dynamo unit.

Curve No. 2.

This curve represents the amperes plotted against the indicated horse power of the engine. When the amperes read zero the horse power reads 14 , this is the friction load.

Curve No. 3.

This curve represents the amperes plotted against the equivalent horse power output of the dynamo.

Curve No. 4.

This curve represents the efficiency of the engine dynamo unit plotted against the indicated horse power of the engine running the dynamo alone.

Curve No. 5.

This curve represents the efficiency of the engine dynamo unit plotted against the indicated horse power of the engine running dynamo, compressor and centrifugal pumps.

Curve No. 6.

This curve represents the efficiency of the engine dynamo unit plotted against the indicated horse power of the engine running dynamo and air compressor.

SUMMARY.Boiler test.

Two boilers connected together and run in parallel.

Type-----Horizontal fire tube.

Date of test-----Feb. 10, 1911.

Duration of test-----10 hours.

Dimensions and proportions.

| | Atlas 100 H.P. | O'Brien 80 H.P.. |
|---|-------------------|---------------------|
| Diameter of boiler----- | 72" | 60" |
| Length of boiler----- | 16 ft. | 16 ft. |
| Width of grate----- | 5 ft. | 5 ft. |
| Length of grate----- | 5 ft. | 5 ft. |
| Number of tubes----- | 72 | 52 |
| Diameter of tubes----- | 3" | 4" |
| Length of tubes----- | 16 ft. | 16 ft. |
| Total grate surface----- | 25 sq. ft. | 25 sq. ft. |
| Total water heating surface----- | 1056 sq. ft. | 997 sq. ft. |
| Percent air in grate----- | 42% | 42% |
| Ratio of water heating to grate surface----- | 42 to 1 | 40 to 1 |
| Area of stack----- | 4.90 sq. ft. | 4.9 sq. ft. |
| Height of stack above grate bars | 72 ft. | 72 ft. |
| Ratio of stack area to grate surface | 5 to 1 | 5 to 1. |
| Method of starting----- | alternate | alternate |

Average Pressures.

Steam pressure gage----- 95.2#
 Absolute pressure-----109.4#
 Barometer pressure----- 14.2#
 Draft in inches of water----- .357"

Average temperatures.

Of external air----- 6°C
 Of escaping gases-----506.05°F
 Of feed water----- 74.7°C

Water.

Total weight of water pumped into boiler
 and apparently evaporated into steam--30207.3#
 Total weight of water actually evaporated
 corrected for the quality of steam---30207.3#
 Equivalent total water evaporated into dry steam from and
 at 212 F ----- 32774.9#
 Equivalent water evaporated into dry steam per
 hour from and at 212 F----- 3277.5#

Fuel.

Cost of coal-----\$2.80 a ton.
 Moisture in coal-----5.10%
 Total coal consumed-----6300#
 Total dry coal consumed-----5960#
 Percent of ash in coal----- 17%
 Total refuse-----1071#
 Total combustible-----4889#
 Dry coal consumed per hour----- 596#
 Kind of coal-----Illinois Bit.

Combustible consumed per hour-----489#

Calorific value of coal-----11150

B.T.U.s per lb.

Calorific value of ash-----1347 B.T.U.s per lb.

Calorimetric tests.

Quality of steam-----could not determine it.

Economic evapoization.

Water actually evaporated per pound of dry coal

from actual pressure and temperature----5.05#

Equivalent water evaporated per pound of coal as

fired from and at 212°F-----5.21#

Equivalent water evaporated per pound of dry coal

from and at 212°F-----5.49#

Equivalent water evaporated per pound of combustible

from and at 212°F-----6.28#

Rate of combustion.

Dry coal consumed per square foot of grate area

per hour-----23.8#

Combustible consumed per square foot of grate

surface per hour-----19.6#

Dry coal consumed per hour per horse power

developed----- 6.3#

Rate of evaporation.

Equivalent water evaporated from and at 212 F per hour

1. Per sq. ft. of grate area-----131.1#

2. Per sq. ft. of heating surface----- 1.5#

Commercial horse power.

Horse power builders rating-----180
 Heating surface per H.P. developed----- 23.1 sq.ft.
 Average horse power developed----- 95

Engine test.

Type-----Corliss
 Made by-----Hamilton Owen Company.
 Makers H.P. rating-----160
 Stroke----- 21 inches.
 Diameter of cylinder----- 14 inches.
 R.P.M. normally-----200
 Piston area-----154 sq.in.
 Clearance-----7/32 in.
 Cut off on normal load----- 1/5
 Efficiency at full load-----about 91%

Dynamo test.

Type-----direct current.
 Voltage designed for-----250
 Amperes designed for-----400
 R.P.M. -----200
 Number of pairs of poles----- 3
 Style of winding-----compound.
 K.W. designed for-----100
 Method of driving-----direct connected.
 Efficiency at full load-----about 92%

Air Compressor.

Style-----cross compound.

Method of driving-----by belt.

R.P.M.-----100

Low Pressure Cylinder.

1. Diameter----- 16 inches.

2. Stroke----- 12 inches.

High Pressure Cylinder.

1. Diameter----- 9 inches.

2. Stroke----- 12 inches.

Piston displacement-----2.77 cubic feet.

Horse power absorbed-----67.20

Horse power output-----25.16

Efficiency----

1. Volumetric-----63.7 per cent.

2. Mechanical-----37.44 per cent.

Air Lift Pump.

Amount of free air used per min.-----176.45 cu.ft.

Amount of water lifted per min.-----290 gallons.

Distance lifted-----181 feet.

Horse power in the air used----- 25.16

Horse power theoretically needed----- 13.25

Efficiency----- 52.66%

General Discussion.

This plant is a paying proposition to the City of Rolla, paying about six hundred dollars a month into the city treasury.

The conditions were by no means perfect the night the tests were made and when the tests were made on the air compressor the high pressure valves were a trifle loose causing a peculiar sound when the air was forced into the receiver tank.

Most of these efficiencies are good for a small plant like this and continuing under the same good management, it ought to continue to be a paying proposition.

Finis.

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